International Journal of New Political Economy 4(2): 1-29, 2023

Investigating Iranian Foreign Trade of Carbon Dioxide from an Environmental Perspective: The Application of an Input output Table (IOT)

Zahra Nasrollahi[1]*, Mehran Zarei[2], Mahbobeh Pourkhalili[3]

ARTICLE INFO

Article history:

Date of submission: 14-11-2022

Date of acceptance: 10-03-2023

JEL Classification:

Q53

F18

C67

Keywords:

Foreign Trade

Input-Output Model

Pollution

Economic Sectors

ABSTRACT

Scientists believe that one of the major causes of instability in global climate conditions is the increase in greenhouse gas emissions, especially carbon dioxide. In this regard, the present study seeks to examine the sustainability of Iran's foreign trade from an environmental perspective using the input-output model. The results show that, in 2016, Iran exported about 33.5 million tons and imported 56.5 million tons of virtual carbon, and the net import of virtual carbon was, thus, 22.9 million tons. In other words, carbon emissions outside Iran's borders to meet the needs of Iranian consumers were about 68% higher than the carbon emissions inside Iran's borders to meet the needs of foreign consumers. Among the economic sectors, the largest exporter of virtual carbon was the chemical materials manufacture sector with an export of about 9.4 million tons, and the largest importer was the metals sector with about 17.4 million tons). In addition, the coke and petroleum products sectors were the largest net exporters, and the basic metals sector was the largest net importer of virtual carbon However, in 2016, the amount of virtual carbon export and import was 173.9 and 93.2 million tons, respectively, and therefore, unlike 2011, Iran this year specifically exported 80.8 million tons of virtual carbon. This year, the largest carbon exporter is the mining sector and the largest importer is the "machinery and equipment not classified elsewhere" sector (91.1 and 18.3 million tons, respectively).

1. Associate professor in Economics, Faculty of Economics, Management and Accounting, Yazd University, Yazd, Iran.
2. Ph.D. Student in Economics, University of Sistan and Baluchestan, Zahedan, Iran
3. MSc in Economics, Department of Economics, Management and Accounting, Yazd University, Yazd, Iran
* Corresponding Author Email Address: nasr@yazd.ac.ir

DOI: https://doi.org/10.48308/jep.4.2.1

1. Introduction

One of the environmental issues of recent years is global warming and climate change, which has become a serious threat to human societies. Scientists believe that a major cause of global instability and global warming is the increase in greenhouse gas emissions, especially carbon dioxide (Stewart & Hessami, 2005; Bacon & Bhattacharya, 2007; Faraji Dizaji & Ousia, 2017). In the meantime, the role of human activities in intensifying the emissions is undeniable. As research has shown, among various human activities, energy consumption accounts for most of the greenhouse gas emissions. The energy sector accounts for two-thirds of the total greenhouse gas emissions and 80% of global CO2 emissions. Therefore, any effort to reduce emissions and mitigate climate change should involve the energy sector (International Energy Agency, 2013). Energy, as the primary input of production, is the main basis of development in any country. In recent years, however, increasing demand for energy and competition for access to it by different consuming sectors has led to the spread of various environmental pollutants, especially in developing countries. This has jeopardized the achievement of sustainable development in these countries. In addition, trade liberalization and the acceleration of the globalization process in recent decades have led to significant growth in economic activities around the world (Kulionis, 2014). Since these activities are associated with large quantities of pollutants, the environmental effects of industrial production and trade of products have come into the focus of many researchers. However, a review of the literature in this area shows that most studies have focused on the relationship between business and the environment at a macro level and regardless of this relationship at a sectoral level. Given the role that trade plays in the redistribution of resources, many researchers believe that assessing the environmental impact of trade with a consumer-based approach can lead to a better understanding of the process of pollution generation as well as appropriate policymaking in this area. In Iran, energy prices have been abnormally low for consumers in domestic, industrial and agricultural sectors for many years. This has been due to the subsidization of oil and gas resources. It has set the per capita energy consumption of the country significantly higher than the world average. For example, the per capita consumption of natural gas and crude oil as well as petroleum products in Iran is 5.6 and 1.6 times the world average per capita respectively. Also, the final per capita energy consumption in agriculture, domestic, public and commercial sectors, transportation and industry is 1.3, 1.8, 1.5 and 1.4 times the world average respectively. Generally, the energy consumption is more than 1.5 times the global average (Ministry of Energy, 2017). Accordingly, assessing the extent of pollution embedded in Iran's trading system can be helpful in sound planning to reduce emissions. For the first time, the present study examines Iran's virtual carbon trade with 165 countries and by 19 economic sectors individually. In other words, carbon trade with each country calculated separately for 19 economic sectors. The input-output model is used for this purpose. It is important to note that this study neglects the “Extraction of crude petroleum and natural gas” sector because the Iranian oil and gas are mainly exported to multinational companies and it is difficult to attribute it to a particular country. Also, since exports and imports of Iranian service sectors are very limited and close to zero, these sectors are not included in the analysis. In addition, Iran's electricity export data are not available in terms of individual countries; hence, excluded from the analysis. To calculate the direct and indirect carbon emissions of the economic sectors, all the sectors in the input-output table are taken into account.

The article is organized as follows: The second section describes the theoretical background and third section presents the literature review. The fourth section presents the research methods and data and fifth section provides the findings. Finally it concludes in section six.

2. Theoretical Foundations

Theorizing the external effects of manufacturing activities dates back to the late 1960s (Ayers & Kneese, 1969; Kagawa, 2012; Owen 2015), when Cumberland (1966) adopted the input-output approach as a useful way of understanding the implications of development processes in the environment (Owen, 2015). The initial static investigations involved an "external impact" vector that only measured the amount of pollution produced per unit of output for each industrial sector (Owen, 2015). In other words, those studies only considered the direct effects of production activities on the environment and did not address the indirect effects. Given the interactions among different sectors, economic activities affect the environment and natural resources indirectly, in addition to their direct effects. Therefore, to eliminate the limitations of earlier studies, traditional data-input models were developed into Environmental Extended Input-Output (EEIO) models to investigate the full (direct and indirect) effects of production activities on the environment. As Duarte & Young (2011) point out, Daly (1968), Leontief (1970), Izard (1972) and Miller & Blair (1985) were the first studies in this field. In recent years, with the development of business communications, many researchers have used input-output models to evaluate the resources embedded in internationally traded goods and services. In this regard, one can refer to Liu and Ma (2011), Gemechu et al. (2013), Li et al. (2014) and Zhao et al. (2016).

2.1. The relationship between the environment and international trade

The environment in different countries of the world is affected by a variety of production, trade and consumption policies. Globalization in recent years has led to the integration of world economies and, thus, increased interactions among countries. Experts believe that, as international trade increases production of goods and services, globalization can increase the environmental costs of economic activity. Accordingly, the environmental impact of international trade has been the focus of various researchers for many years (Copeland & Taylor, 2013; Geng et al., 2017). International trade may not only create its own environmental issues but it can also increase resource imbalances among trading partners, as developed countries try to seize the cheap resources of other countries while trading with them (WTO, 2011; Geng et al., 2017). In fact, the increase in the speed of production of goods as a result of the expansion of global business activities has led to numerous environmental problems that sometimes seem irreparable. Research has shown that a significant and increasing share of global pollution comes from the production of goods and services traded internationally. Although this increase in the production of goods and services may directly result in an increase in international trade, this can have unintended consequences for climate policy, as it results in a spatial separation between production and consumption (Peters et al., 2011). Phenomena such as carbon leakage, pollution shelter hypothesis, difficulty in calculating carbon reduction, and the like are some of the undesirable consequences of the geographical separation of production and consumption. A major cause of this separation is the emphasis of international treaties on the distribution of production-induced emissions across regions.

For example, the Kyoto Protocol, as part of the United Nations Framework Convention on Climate Change (UNFCCC), is one of the most important international measures to reduce global emissions. According to its Annex I, the member states are required to reduce their emissions by 2.5% below 1990 levels in the first year of their commitment period (2000-2012). Although statistical studies have shown a steady trend of pollution in developed countries, pollution has increased rapidly since 1990, compared to the last decade. In this regard, developing countries (i.e. countries with little or no commitment), as providers of developed countries, have increased their emissions and have, thus, been considered responsible for the increase in global emissions. The fact that the reduction of emissions in Annex I countries is often offset by the shift in production or by import substitution is often overlooked (Ahmad & Wyckoff, 2003; Vlčková et al., 2015). Since most commodities traded internationally are averagely carbon-intensive, even when the targets set in the Kyoto Protocol are implemented, greenhouse gas emissions can increase internationally (Vlčková et al., 2015). Therefore, the important issue that needs the attention of the international community is to determine what share of the output of non-Annex I countries is consumed by Annex I countries, thereby allocating the carbon reduction responsibility appropriately and equitably to the countries of the world.

2.2. Emission based on production and consumption

Generally, there are two approaches used on the basis of production and consumption to measure GHG emissions. They are addressed below to clarify how they impact climate policies.

a. **Production-based approach:** Production-based emissions are those from domestic production (i.e. within a country's economic boundaries) for domestic and foreign consumption. In other words, this approach considers the release of CO2 at one point of production, no matter where the goods are used or who ultimately uses them (Atkinson et al., 2011; Steininger et al., 2014; Mi et al., 2016). In this approach, since the emission estimates are based on the geographical location of the emission, any external cost associated with the production of exported products is ignored. The approach has been widely used in global climate change agreements, including the UNFCCC and the Kyoto Protocol.

b. **Consumption-based approach:** In contrast to the production-based approach, under the consumption-based one, all the emissions released along the production and distribution chain are attributed to the end-user of the products (Wiedman, 2009; Mi et al., 2016). In other words, apart from the geographical location of production, consumers are responsible for any contamination associated with the production of the goods and services that they consume (Gemechu et al., 2013). Consumer responsibility, therefore, covers not only the emissions of all the products produced domestically for domestic consumption but also the emissions of the products imported from other countries for domestic consumption.

According to these definitions, the main difference between the two approaches is that, in the second approach, the policy of reducing emissions in a country entails transferring the responsibility for the emissions in the production of export goods and services and accepting the responsibility for the 'embedded' or 'virtual' emissions in imported goods and services (Steininger et al., 2014; Afionis et al., 2017). The difference between production-based emissions and consumption-based emissions shows the net effect of embedded trade emissions (EETs). In other words, the net effect of embedded emissions on trade is equal to the difference of the emissions embedded in imports (EEI) from the emissions embedded in exports (EEE). A positive difference indicates the net exported emissions while a negative value represents the net imported emissions (Davis & Caldeira, 2010).

3. Literature Review

The topic of virtual carbon trading does not have a long history in academic literature. Most studies in the field of calculating virtual carbon trading have been carried out since the mid-2000s. These studies mainly calculated the virtual carbon trade between different regions based on the carbon footprint concept.

Wiedmann (2009) points out that over the last decade there has been a tremendous increase in applications of analytical models based on environmentally extended input–output technique. He believes advantage of input–output based analysis is that it is possible to provide a quantitative consumption perspective of virtually any economic activity. So the input-output technique is a good tool for carbon footprint analysis. Atkinson et al. (2011) estimated virtual carbon flows in domestic production technologies and the pattern of international trade using input-output analysis. Their results show that a tax on virtual carbon could lead to effective tariff rates on the exports of the most carbon-intensive developing nations. if virtual carbon is taxed at $50/ton CO2, then the effective tariff rates faced by developing country exports is significant, up to 10% of the value of the average export bundle, and two to three times this level for specific tradable sectors. Sadeghi et al. (2015) investigated economic sectors carbon footprint trade balance by using Social Accounting Matrix 2011. Results indicate that in 2011, the negative trade balance of the country's carbon footprint is 4.5 tonnes. Sector of oil, natural gas distribution, manufacture of chemicals and chemical products, transport have a highest positive carbon footprint trade balance and food products, manufacture of motor vehicles, trailers and semi-trailers, manufacture of basic metals have the most negative The carbon trade balance. Liu et al. (2017) investigated the flows of virtual carbon and water implicit in international trade. They conclude global trade can reduce pressure on the environment if imported products are produced with less carbon emission intensity and less water consumption compared to domestic production. Momeni et al. (2017) examined the state of sustainable development in Iran using carbon footprints index. The results based on inpu-outpu method shows that per capita carbon footprint in Iran has decreased in 2011 than 2016 which it is result of reduction of CO2 emissions of imports. Reduction of CO2 emissions is arising from imports of “Coke coal and petroleum” and “machinery and equipment” sectors. Altogether, results indicate that decrease CO2 emissions of imports and increase CO2 emissions of internal production in 1390 than 1385.

Zhang et al. (2020) assessed the impacts of carbon trading on economic output and carbon dioxide emissions reduction in China's industrial sectors by the data envelopment analysis (DEA). This was done on the basis of three carbon trading schemes: no trading (NT), sectoral trading (ST), and sectoral-and-temporal trading (STT) during 2006–2015. The results indicate that, the ST and STT schemes comparing with the no-trading scheme, may create potential gains of 268.02 and 612.26 trillion yuan in the whole industrial i.e., the industrial value-added would be increased by 55.17% and 73.76%, respectively. Also, The ST and STT schemes could reduce 17.17 and 19.22 billion tonnes of carbon dioxide emissions

Zhao et al. (2021) assessed virtual carbon and water flows embodied in the global denim-product trade. They quantified footprints of denim production by life-cycle assessment and water footprint assessment. The results showed that virtual carbon embodied in the global denim trade increased from 14.8 Mt CO2e in 2001 to 16.0 Mt CO2e in 2018, and the virtual water consumption increased from 5.6 billion m3 to 4.7 billion m3 from 2001 to 2018.

Tian et al. (2022) explores the relation between water utilization, energy consumption, and carbon emission in China, based on a multiregional input–output (MRIO) analysis. Their results show that water, energy, and carbon (WEC) present significant consistency in production and consumption processes. Sectors with higher consumption coefficients dominate the transfer of virtual WEC. Virtual WEC transfers from less developed regions to developed regions. De Bertoli and Agez (2023) illustrate Environmentally-Extended Input-Output (EEIO) analysis' usefulness to sketch transition plans on the example of Canada's road industry. They show in their article that construction sector carries the second-highest environmental impacts of Canada (8–31% depending on the indicator) after the manufacturing industry (20–54%). The road industry generates a limited impact (0.5–1.8%), and emits 1.0% of Canadians' GHGs, mainly due to asphalt mix materials (28%), bridges and engineering structures materials (24%), and direct emissions (17%). Pavement construction and maintenance only explain 5% of the life cycle carbon footprint of Canada's road network, against 95% for the roads' usage (72% from vehicle tailpipes releases, 23% for manufacturing vehicles).

The present study for the first time, examines Iran's virtual carbon trade with 165 countries and by 19 economic sectors individually. In other words, Iran’s carbon trade with 165 country calculated separately for 19 economic sectors. For this purpose, the output- input technique has used

4. Methodology

4.1. Input output model

In general, the input-output model is based on the idea that the national or regional economy can be subdivided into a number of correlated sectors whose relationships are expressed in a mathematical matrix (Kulionis, 2014). The following equation illustrates the basic mathematical structure of the input-output model and describes the relationship between the output of economic sectors and other related sectors and the final demand (Chen et al., 2018).

$$X_i = \sum_{j=1}^{n} Z_{ij} + F_i \tag{1}$$

In this equation n denotes the number of economic sectors, and X_i is the total output of sector i which can be used for intermediate and final demands. Also, Z_{ij} and F_i represent intermediate and final demands respectively. Under the assumption of a linear production function, a_{ij} is defined as the technical coefficient, which represents the direct demand of sector j of the input of sector i to produce an output unit:

$$a_{ij} = \frac{Z_{ij}}{X_j} \tag{2}$$

According to Formula (2), equation (1) can be expressed as follows:

$$X_i = \sum_{j=1}^{n} a_{ij} X_j + F_i \tag{3}$$

The matrix form of the above equation can be expressed as follows:

$$X = AX + F \tag{4}$$

Where *X*, *A* and *F* represent the output vector of different economic sectors, the direct technical coefficients matrix, and the final demand vector respectively.

Equation (4) can be rewritten as follows:

$$X = (I - A)^{-1} F \qquad ; make\ B = (I - A)^{-1} = [b_{ij}] \tag{5}$$

In this formula, *I* is called the single matrix, and $(I - A)^{-1}$ is referred to as Leontief inverse matrix, which shows the full effect of the change in the net final demand on all activities. Also, b_{ij} represents the total (direct and indirect) output of sector *i* which is required to raise a final unit of demand in sector j (Zhao et al., 2009). Hence, the relationship between the final demand and the output is established by the Leontief coefficient.

In this study, the 2011 input-output table was used to achieve the desired goals. This table is the most up-to-date input-output table of the country which includes 99 economic sectors. It has been integrated into 26 sectors in accordance with the available statistics on CO_2 emissions.

4.2. Calculation of the export and import of CO_2 embedded in the economic sectors of the country in terms of individual EU member states

In the present study, we use the method proposed by Chen et al. (2018) to calculate the imports and exports of embedded emissions among different economic sectors and in terms of individual EU member states. The calculations are performed by equation (6) (*ibid*):

$$K_E = k(I - A_d)^{-1}E_d = fE_d \quad (6)$$

Where KE, k and Ed represent virtual carbon exports, direct carbon intensity and export value respectively. The calculation of these items is explained below. To calculate the virtual carbon exports of different economic sectors using the input-output model, it is first necessary to make changes in the standard structure of the input-output table used by the research. This table contains certain amounts of the imported products in the final demand and the intermediaries of all the economic sectors. When calculating the exports and imports of virtual carbon, it is necessary to separate domestic products from imported products. For this purpose, the following relationship has been used to obtain the desired internal variables (Banouei, 2012; Chen et al., 2018):

$$d = \frac{x - e}{Z_e + F_h} = \frac{x - e}{x - e + m} \quad (7)$$

In this equation, x, e and m represent the output, export, and import values of the country respectively. Also, Z_e and F_h indicate the intermediate and final consumption values respectively. The ratio d in this relation has an internal origin, and multiplication by any variable gives the internal ratio of that variable. In Table (1), the modified form of the input-output table is shown for a hypothetical three-part economy.

Table 1. Modified form of the input-output table for a hypothetical three-part economy

	sectors			**Final consumption**		**Domestic production**
	1	**2**	**3**	**Final domestic demand**	**Exports**	
Sector 1	D11	D12	D13	DF1	E1	X1
Sector 2	D21	D22	D23	DF2	E2	X2
Sector 3	D31	D32	D33	DF3	E3	X3
Imports	M1	M2	M3	Mf	·	M
Value added	V1	V2	V3			
production	X1	X2	X3			
CO_2 pollution	L1	L2	L3			

Source: Banouei et al. (2013)

In the table above, *Dij* and *Dfi* represent the matrix of the intermediate trade between the domestic sector and the final domestic demand, each obtained on the basis of relation (7). In the present study, in order to modify the National Input-Output Table in accordance with the above table, the CO_2 data of each sector are added to the table as a vector line. After the desired adjustments are made, the calculation process is performed as follows:

$$\varphi = [K_i] \text{ و } K_i = \frac{\varphi_i}{X_i} \qquad (8)$$

In the above relation, X_i and φ_i represent the total output and the total carbon emission of the part *i* respectively. Also, *Ki* represents the direct carbonization of the iM sector and suggests the total amount of CO_2 released directly to increase the monetary output of the iM sector.

The next step is to calculate the amount of CO_2 released as a result of the increase in the final demand for the Jm sector. Indeed, it means the determination of the total CO_2 emitted from all the economic sectors directly and indirectly to increase one unit of final demand in sector *j*. The following relation has been used for this purpose:

$$\varepsilon_j = \sum_{i=1}^{n} K_i b_{ij}^* \, ; f = [\varepsilon_j] \tag{9}$$

In this equation, Ki and bij* represent the direct carbonization of the economic sectors and the multiplier coefficient of domestic production respectively. Also, εj is the total carbonization of the jm sector. Its difference from the direct carbonization is used to obtain the indirect carbonization of sector j. The multiplier coefficient matrix of the domestic production in the above relation shows the total (direct and indirect) effect of the increase in one unit of the final domestic demand per sector on the output of all the economic sectors. It can be represented by equation (10):

$$B = (I - A_d)^{-1} = b_{ij}^* \tag{10}$$

In the above equation, A_d represents the matrix of the internal direct technical coefficients obtained through relation (7).

The final step is to multiply the total export value of all the economic sectors (Ed) by the total carbonization of these sectors (D). In the case of Ed in equation (6), it is important to note that, since some intermediate imports are used to produce export products, not all of the pollutants embedded in the intermediate imports are released by the final domestic demand; rather, part of it is released to meet the foreign final demand. Therefore, as mentioned earlier, the export matrix needs to be extracted from the import matrix; thus, the export matrix in equation (6) is obtained by relation (7). This matrix is represented in equation (11):

$$E_d = diag\left(1 - \frac{m_i}{X_i + m_i - e_i}\right) E \tag{11}$$

Given the economic structure of Iran, however, it is important to note that imports for re-export can be considered zero (Banouei, 2012). Therefore, in the calculations of this research, the coefficient d is considered one in the above relation.

The following relation is used to obtain the CO_2 embedded in the country's imports:

$$K_m = K(I - A_d)^{-1}m \quad (12)$$

Finally, the embedded net CO_2 exports are obtained from equation (13):

$$N_k = K_E - K_m \quad (13)$$

4.3. Research Data

In order to achieve the research goals, three types of statistical bases are used as follows:

1) The input-output table of 2011 and 2016. The office of Statistical Center of Iran, with a ten-year rotation, provides the input-output table of Iran. The latest is for 2011, which includes 99 sectors. In this study, these sectors were aggregated in 26 sectors. For 2016, the table published by Central Bank of Iran has been used
2) Pollution (CO_2) emission data in different economic sectors extracted directly from the 2011 and 2016 Energy Balance and Hydrocarbon Balance Report. Since this study assumes that there is a direct relationship between energy consumption and emissions (CO_2), the energy consumption serves as a basis for the adjustment of CO_2 and the emission of CO_2 is calculated in terms of individual economic sectors with regard to the emission coefficients approved by the Environmental Protection Agency and based on the 2011 Guidelines of the Intergovernmental Panel on Climate Change (IPCC). Since these coefficients are not published for years after 2011, it is assumed that these coefficients in 2016 are the same as in 2011 and have not changed.

3) Data on Iran's exports and imports in 2011 and 2016 in terms of individual countries, provided by the customs office. These data are classified according to HS codes. To match exports and imports data with the input-output table, HS codes were converted to ISIC4.

5. Analysis of the results

Table 2 presents the findings on the virtual carbon emission and trade for each economic sector. According to the table, the sectors of "Other Mines", "Manufacture of Non-Metallic Mining Products" and "Manufacture of Basic Metals" had the highest direct carbon emissions (0.219, 0.125 and 0.04 ton/million Rials respectively), But if we consider the mutual relations between the economic sectors and also consider the indirect carbon emission, a different picture of the amount of carbon emissions of the economic sectors will appear. The sectors "food and beverage products", "manufacturing of basic metals" and "fabricated metal products except machinery" have the highest total carbon emission (direct and indirect), these sectors also accounted for the largest total carbon footprints 0.270, 0.218 and 0.163 respectively. The exports and imports of Iranian virtual carbon in 2011 were about 33.5 and 56.5 million tons. Thus, Iran's net import of virtual carbon was 22.9 million tons in that year. In other words, the amount of carbon produced for the production of imported products was about 68 percent more than the carbon produced for the exporting of products.

But in 2016, the amount of export of virtual carbon was more than its import (173.9 and 93.2 million tons, respectively), so that Iran was the exporter of virtual carbon in the amount of 80.8 million tons this year. In other words, carbon exports have grown by 420% over the past five years, but imports have grown by only 65%. In 2011, the amount of carbon produced per one million rials of import was 0.09, but in 2016, this amount decreased to 0.07. Therefore, Iran's imports have generally tended towards greener imports. But on the other hand, the carbon index of Iranian rial exports has reached 0.09 units in 2011 to 0.13 units in 2016. In other words, Iran's exports have moved towards polluting products.

Table 2. Some carbon indicators in Iran's economic sectors :Comparison of 2011 and 2016

Row	Activity field	Carbon emissions-Thousand-Tons	Direct carbon intensity-Ton to million Rials	Direct and indirect carbon intensity	Carbon export Thousand- Tons 2016		Carbon Import Thousand- Tons		Net Export	
					2011	2016	2011	2016	2011	2016
1	agriculture	38,297	0.018	0.047	2,117	5,007	2,367	7,810	-250	-2,803
2	Other Mining	37,161	0.219	0.024	3,765	91,114	664	1,407	3,101	89,706
3	food products, beverages and tobacco	14,082	0.014	0.270	1,590	10,375	4,421	7,263	-2,831	3,112
4	Manufacture of textiles	1,394	0.010	0.060	859	1,691	472	1,516	387	175
5	Manufacture of wearing apparel	170	0.002	0.058	42	42	16	56	26	-14
6	Tanning and dressing of leather	331	0.006	0.026	153	158	22	28	131	130
7	wood and products of wood	455	0.004	0.030	11	90	381	828	-370	-737
8	paper and paper products, Printing and reproduction of recorded media	2,908	0.024	0.038	52	136	1,313	2,539	-1,261	-2,403
9	Manufacture of coke, refined petroleum products and nuclear fuel	8,034	0.012	0.072	3,643	4,941	425	123	3,218	4,818
10	Manufacture of chemicals and chemical products	32,254	0.032	0.032	9,431	25,520	7,660	15,212	1,771	10,308
11	rubber and plastics products	1,940	0.007	0.079	638	2,483	1,000	2,266	-362	218

Row	Activity field	Carbon emissions-Thousand-Tons	Direct carbon intensity-Ton to million Rials	Direct and indirect carbon intensity	Carbon export Thousand- Tons 2016		Carbon Import Thousand- Tons		Net Export	
					2011	2016	2011	2016	2011	2016
12	Manufacture of other non-metallic mineral products	47,464	0.125	0.070	3,770	10,208	1,729	3,609	2,042	6,599
13	Basic Metals	28,212	0.040	0.218	5,584	18,953	17,374	15,075	-11,790	3,878
14	fabricated metal products, except machinery and equipment	1,398	0.004	0.163	392	934	1,412	2,112	-1,019	-1,179
15	Manufacture of computer, electronic and optical products	167	0.006	0.071	56	140	2,542	5,144	-2,486	-5,003
16	Manufacture of electrical equipment	730	0.004	0.038	275	667	1,838	3,468	-1,563	-2,801
17	Manufacture of machinery and equipment n.e.c.	1,661	0.012	0.064	608	1,068	10,062	18,364	-9,454	-17,296
18	Manufacture of motor vehicles, trailers and semi-trailers and other transport equipment	1,946	0.003	0.069	162	239	2,364	5,150	-2,202	-4,911
19	Manufacture of furniture; manufacturing n.e.c	644	0.004	0.047	380	142	398	1,186	-17	-1,044
Total		999,258	0.546	1.729	33,530	173,907	56,459	93,156	-22,929	80,751

Source: Research calculations

Among the economic sectors, the largest exporter of virtual carbon was the "Manufacture of Chemicals and Materials" with about 9.4 million tons of export, and the largest importer was the "Basic Metals" with about 17.4 million tons. In addition, the coke and petroleum products sector was the largest net exporter, while the basic metals sector was the largest net importer of virtual carbon. But in 2016, the largest carbon exporter is the mining sector and the largest importer is the "machinery and equipment not classified elsewhere" sector (91.1 and 18.3 million tons, respectively).

In 2011, Iran had commercial relations with 177 different countries, but in 2016, the number of Iran's trading partners was 163 countries[1]. Table 2 presents Iran's virtual carbon trade with each of those countries for 19 sectors. Due to the limited scope of this paper, it is not possible to display all the details in this regard. Therefore, based on their geographical locations and the amount of their trade with Iran, the countries of the world are classified into eleven regions. The results are presented in terms of these regions. Appendix (1) shows the countries of these regions. Also, the 19 economic sectors evaluated in this study are categorized into eight sectors. Fig 1, shows the exports of Iranian virtual carbon to different regions in eight economic sectors for 2016. The calculations showed how much carbon was released in Iran for the sake of foreign consumption. According to the results obtained, Iran's largest export of virtual carbon was to the MENA (the Middle East and North Africa) countries, which amounted to about 50.2 million tons. In other words, most of the virtual carbon produced in Iran was for the consumption of the citizens in the MENA countries rather than for the domestic citizens. China and India were in a place next to the MENA countries. In total, Iran exported about 40.9 million tons of virtual carbon to them. The largest share of the Iranian virtual carbon exports to the MENA countries belonged to mineral products, while more than 55% of such exports to China and India related to chemical products.

1. Of course, in the data of the Iranian Customs Department, in addition to this number, there is also a line dedicated to other foreign countries, the volume of which is not significant, and it is not clear which countries it includes.

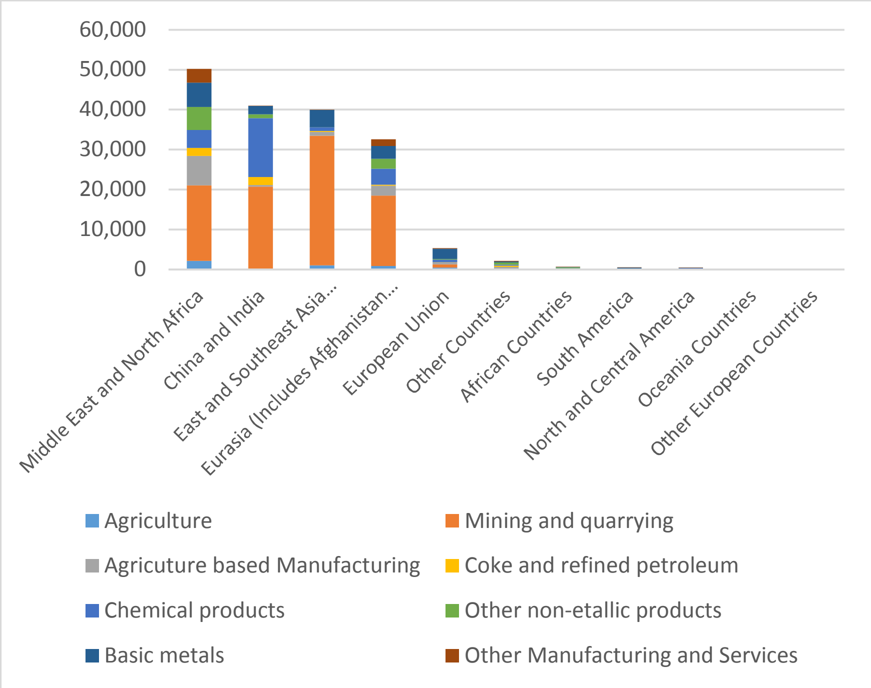

Fig 1. Export of virtual carbon to different regions of the world (in thousands tons)

Fig 2, shows the amount of the virtual carbon imports from different regions in 2016. As found through calculations, about 173 million tons of carbon was released in foreign countries for the consumption of Iranian citizens. The figure also shows the spatial sources of the emissions. As the graph suggests, most of Iran's virtual carbon imports came from the China and India countries. In total, these countries exported about 30.5 million tons of virtual carbon to Iran, which is about 32 percent of Iran's total imported carbon. Other industry were the major constituent of Iran's virtual carbon imports from MENA, accounting for more than 46 percent of the total imports from the region. The EU was the second largest exporter of virtual carbon to Iran, with a volume of about 17.8 million tons 46% of which related to the "other metals" sector.

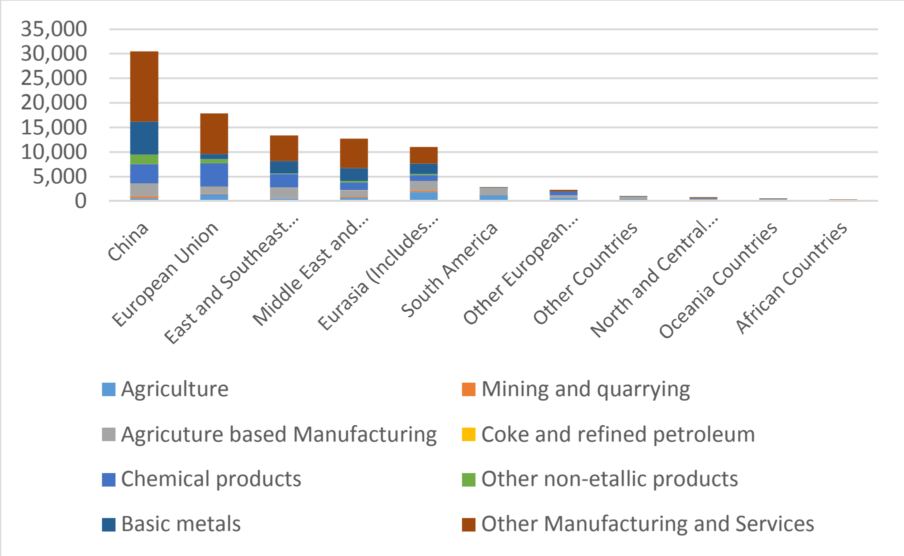

Fig 2. Import of virtual carbon to different regions of the world (in thousands tons)

The net virtual carbon export values are presented in Fig 3. The largest net virtual carbon exports of Iran were to MENA countries; they amounted to 37.5 million tons. On the other hand, most of the net imports of that material were from the EU countries, exceeding 12.55 million tons.

6. Conclusions and suggestions

Increase of greenhouse gas emissions despite international conventions and measures to reduce emissions has recently put spotlights on the demand-side management of how pollutants are emitted and distributed. In this regard, establishing a low-carbon economy has become increasingly important. In addition, the role that trade has played in the redistribution of carbon emissions over the recent decades has made many global researchers pay attention to demand-side management approach to the environmental assessment of trade. In the meantime, virtual carbon trading, as an economic-environmental indicator, has made it possible to assess the impact of international trade on emissions by linking pollutant emissions, industrial production and international trade (Ghafouri, 2016). With respect to the potential that exists in this part of commerce, it can be used as a tool to reduce emissions and, consequently, achieve sustainable development. Considering Iran's position in the world in terms of oil and gas production and the large amount of emissions resulting from it, the present study has attempted to calculate the virtual carbon trade of the country in terms of each economic sector and country.

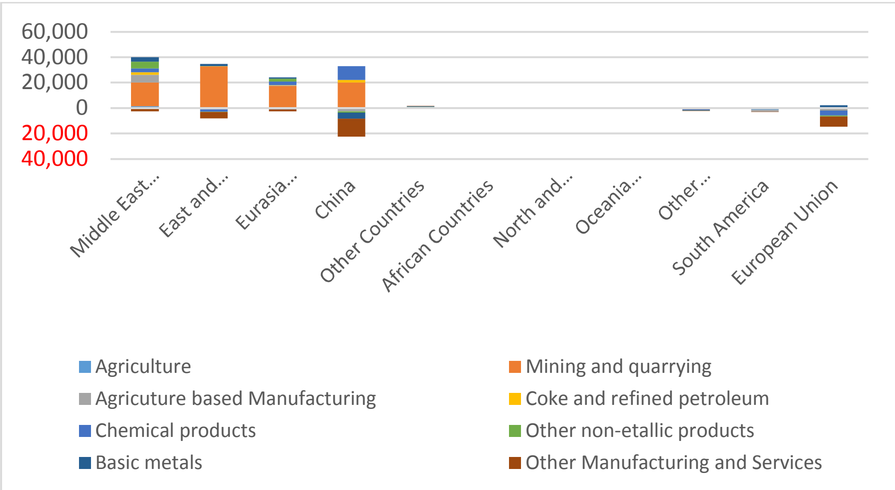

Fig 3. Net virtual carbon exports to different regions of the world (in thousands tons)

The results showed that, in 2011, Iran exported about 33.5 million tons and imported 56.5 million tons of virtual carbon. Thus, its net import of virtual carbon was 22.9 million tons. In other words, carbon emissions outside Iran's borders to meet the needs of Iranian consumers were about 68% higher than the carbon emissions inside the country to meet the needs of foreign consumers. Among the economic sectors, the largest exporter of virtual carbon was the manufacture of chemicals and materials sector with about 9.4 million tons, and the largest importer was the metals sector with about 17.4 million tons. In addition, the coke and petroleum products sectors were the largest net exporter, while the basic metals sector was the largest net importer of virtual carbon. However, in 2016, the amount of virtual carbon export and import was 173.9 and 93.2 million tons, respectively, and therefore, unlike 2011, Iran this year specifically exported 80.8 million tons of virtual carbon. This year, the largest carbon exporter is the mining sector and the largest importer is the "machinery and equipment not classified elsewhere" sector (91.1 and 18.3 million tons, respectively).

Concerning the location of virtual carbon exports and imports, the results showed that Iran's largest virtual carbon exports were to the MENA countries; they amounted to about 10.5 million tons and in 2016 it is about 50.2 million tons. China and India were in the next place; they received Iran's exports of about 10 million tons of virtual carbon, which reached 40.9 million tons in 2016. Non-metallic mineral products constituted the largest share of the Iranian virtual carbon exports to the MENA countries, while the largest share in 2016 was related to mining. More than 55% of the country's virtual carbon exports to China and India belonged to chemicals. It was also shown that in 2011 about 57 million tons of carbon was released in foreign countries to supply Iranian citizens; this amount has reached about 93 million tons in 2016. In 2011, most of the virtual carbon imports to Iran were from the MENA region (with about 18.4 million tons of imports), but in 2016, the main sources of Iran's virtual carbon imports were India and China, which exported a total of 30.5 million tons of virtual carbon to Iran. Since the sectors of "food products, beverages and tobacco", "Basic Metals" and "fabricated metal products, except machinery and equipment" have high carbon intensity (direct and indirect), It is suggested that their production technology be improved to reduce carbon emissions. Furthermore it is suggested that in the Iranian trade policy, pattern of trade should be changed and high carbon-intensive products must be imported instead of the producing them in Iran.

Funding

This study received no financial support from any organization.

Authors' contributions

All authors had contribution in preparing this paper.

Conflicts of interest

The authors declare no conflict of interest

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Appendix 1

Table A. In the table below, it is shown which countries are included in each of the regions mentioned in this research.

Abbreviated title	full title	Member countries
ESA	East and Southeast Asia Countries	Vietnam, Hong Kong, Malaysia, Myanmar, Macau, Philippines, Singapore, Japan, Republic of Korea, Taiwan, Thailand, Indonesia, Brunei (Dar es Salaam)
OC	Other Countries	Bangladesh, Bhutan, Pakistan, other foreign countries, Sri Lanka, Papua New Guinea, Maldives, Nepal, Reunion
CHI	China and India	China and India
EUR	Eurasia (Includes Afghanistan and Uzbekistan)	Belarus (White Russia), Armenia, Uzbekistan, Afghanistan, Ukraine, Azerbaijan, Tajikistan, Turkmenistan, Turkey, Republic of Moldova, Russian Federation, Kyrgyzstan, Kazakhstan, Georgia, Mongolia
EU28	European Union	Austria, Spain, Estonia, Slovakia, Slovenia, England, Italy, Ireland, Germany, Belgium, Bulgaria, Portugal, Czech Republic, Denmark, Romania, Sweden, France, Finland, Cyprus, Croatia, Poland, Luxembourg, Lithuania, Malta, Hungary , Dutch, Scotland
OEC	Other European Countries	Republic of Macedonia (Yugoslavia), Latvia (Latvia, Iceland, Albania, Bosnia and Herzegovina, Switzerland, Serbia, Norway, Liechtenstein, Monaco, Yugoslavia
Mena	Middle East and North Africa	Jordan, Algeria, United Arab Emirates, Bahrain, Tunisia, Libyan Arab Jamahiriya, Syrian Arab Republic, Suriname, Iraq, Saudi Arabia, Oman, Qatar, Kuwait, Lebanon, Morocco, Egypt, Yemen
AF	African Countries	Ethiopia, Uganda, South Africa, Benin, Botswana, Burkina Faso, Togo, United Republic of Tanzania, Djibouti, Central African Republic, Chad, Rwanda, Zambia, Zimbabwe, Ivory Coast, Namibia, Malawi, Seychelles, Nigeria, Niger, Mozambique, Mauritius, Mali, Mauritania, Madagascar, Liberia, Guinea, Gambia, Gabon, Comoros, Kenya, Congo, Senegal, Swaziland, Sudan, Somalia, Sierra Leone, Ghana, Cambodia
SAM	South America	Uruguay, Ecuador, Argentina, Brazil, Bolivia, Paraguay, Peru, Chile, Colombia, Guyana, Venezuela
NCA	North and Central America	Nicaragua, Costa Rica, Puerto Rico, Panama, Aruba, Honduras, Mexico, Guatemala, Cuba, Canada, Dominican Republic, Jamaica, United States of America
OCE	Oceania Countries	Australia, Fiji, New Zealand